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## Objective

When a human is interacting physically with a robot (cobot or exoskeleton), his/her posture is inevitably influenced by the robot movement when the two accomplish a task. Among the possible movements that the human could do to follow the robot's end-effector movement, some could be risky from an ergonomics point of view, and the robot should be able to predict those before executing a movement. The question is: how can the robot predict what will be the human posture corresponding to a given robot trajectory? Since the human is not controllable, an active robot imposing a trajectory during collaboration should predict the human joint state and evaluate the ergonomics risk associated to the predicted posture before deciding about its movement.

We propose a method to estimate in probabilistic terms the human postures during human-robot collaboration, providing as well a probabilistic evaluation of the associated ergonomics scores.

## Significance

Human Robot Collaboration (HRC) has the potential to improve the working conditions of operators by optimizing the robot movements for both the task performance and the human ergonomics, thus reducing the risk of muscle-skeletal diseases. Our method enables a more appropriate evaluation of the impact of robot collaborators for humans from the point of view of ergonomics:

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a probabilistic approach for computing human postures during robot collaboration is necessary to have a more realistic estimation of the ergonomics risk for these postures. This ergonomics prediction must be also personalized for different human operators. Our method impacts the design of user-specific robotic workstations and robot controllers that take into account human factors.

# Methods

The probabilistic estimation of the human posture is formalized as an estimation of the human joint velocity $\dot{q}$ given the current joint configuration $q$ and the end-effector velocity $\dot{x}$. This problem could be solved by applying inverse kinematics, but previous approaches do not consider the redundancy of the human model and do not allow to integrate past experiences. Data-driven approaches could enable to integrate past experience, but the main limitation of previous approaches is that they could not guarantee the non-violation of the kinematic constraints imposed by the end-effector position. We propose is a data-driven approach that: (1) solves the redundancy of the human model by returning a distribution of the joint velocities (2) which satisfy the kinematic constraint imposed by the end-effector velocity. The key idea of our algorithm is to learn a distribution over null-space movements, i.e. the movements which do not change the end-effector position but do change in the joint space because of the intrinsic human body redundancy. To do that we applied the combination of a Gaussian Process a gradient-free method for the optimization of the parameters.

# Results and discussion

We tested our method for predicting the human joint velocities in a HRC scenarios where a human collaborates with a Franka robot in a pick & place task. We compared our method with model-based inverse kinematics, state-of-the-art data-driven approaches (Gaussian Processes) which directly execute regression on the original space of the joint velocities and with a sampling based method. The results show that our method is more accurate in the prediction of the human joints while satisfying the kinematic constraints and human-robot coupling constraints. The prediction of the ergonomics scores is thus also more accurate and informs better a robot for designing appropriate trajectories.